

Enabling Technologies

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Abell 2218, a rich galaxy cluster and a spectacular example of gravitational lensing. Light passing through the cluster is deflected by its enormous gravitational field, much as an optical lens bends light. This causes the arc-like pattern spread across the picture like a spider web. Image: NASA/HST

**...to invent tools for
a new age of discovery.**

The Origins technology program will develop the means to achieve the most ambitious and technically challenging measurements ever made. These developments envisage new methods to gather signals from distant sources, precise control of optical elements to a precision of one-thousandth of a human hair, and measurements of distances between optical elements to the width of a hydrogen atom. Such exquisite techniques require methods and tools that do not exist today. Building spacecraft of the future incorporating these technologies will exploit the creative inventiveness of our scientists as well as the care and precision of our engineers.

The technology plan has two strategic objectives. In the near term, the maturing technologies for observatories such as the Space Interferometry Mission (SIM), the James Webb Space Telescope (JWST), and the Terrestrial Planet Finder (TPF) must be completed and tested. It is also critical to begin establishing the new technological building blocks for the very large space observatories described elsewhere in this roadmap that are envisioned to follow our current missions. Remarkable progress has been made toward the near term objectives. However, the longer term objectives are not yet within our grasp. Creating the technological capabilities to realize the observatories of the future will require a new technology initiative. This initiative will develop advanced detector arrays to convert the light into electrical signals; build large, lightweight mirrors; actively control the surface errors of the mirrors and optical elements to produce an almost perfect aperture; and provide cooling techniques to eliminate the infrared emission from the optical surfaces of a warm telescope. These four areas of focused technology development will provide the basic capabilities for a broad range of future space observatory architectures.

Accomplishments Following the Previous Roadmap

Over the past five years, technology developments leading towards the Origins missions have been remarkably successful. The successes have been both technical and institutional. Not only have new space observatory components and capabilities been developed, but also a number of valuable new partnerships with other government interests have emerged.

HST is now the beneficiary of cryocooler advances that have allowed the reactivation of the NICMOS instrument and large format CCD detectors that have increased the useable field of view of the telescope. The Space Infrared Telescope Facility (SIRTF) mirror is fabricated from a form of beryllium metal that is optimized for cryogenic optical system applications. This is a technology that was initially studied and developed with the help of NASA's Aerospace Technology Enterprise. SIRTF will carry improved infrared detector arrays that are derived from technology originally developed by the Department of Defense (DoD).

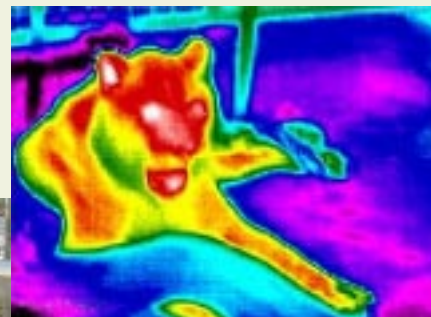
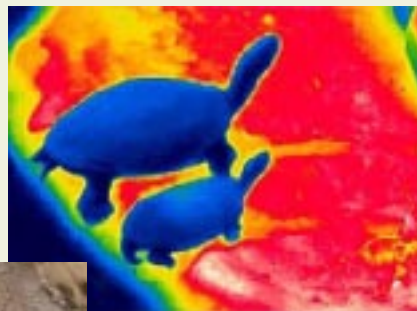
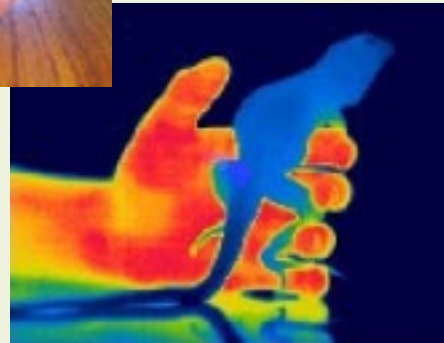
Do Animals Glow in the Dark?

Have you ever wondered what animals look like in the dark? The Education and Public Outreach Office of NASA's SIRTf mission has created an infrared zoo on the web. This website has received numerous awards and the seal of Good House-keeping magazine.

Infrared light shows us the heat radiated by the world around us. By viewing animals with a thermal infrared camera, we can actually "see" the differences between warm- and cold-blooded animals. Infrared also allows us to



study how well feathers, fur, and blubber insulate animals. Visitors to the "Infrared Zoo" see what new information you can gather about the animals here that you would not get from a visible light picture.



Through its inventive use of technology SIRTf involves students in science and encourages conversations that span discipline boundaries. This is just one example of the multidisciplinary educational materials that are produced with the goal of engaging the young minds of the future scientists.

JWST has sponsored significant work on demonstrating an array of 2,000 by 2,000 near-infrared detectors which will benefit other IR missions.

Recent achievements in precision metrology and reduction of microdynamic disturbances will enable the SIM mission to achieve its goal of measuring ultra precise stellar positions.

Progress towards the primary mirror for JWST has come on two fronts. The Advanced Mirror System Demonstrator project, a partnership between NASA and DoD, has produced a number of options for rapid fabrication of lightweight, 2-meter mirror panels. These are the building blocks for large apertures, such as JWST, that must be folded to fit into the payload space of affordable rockets. In parallel, techniques have been demonstrated to deploy a folded mirror and align panels automatically in space to the accuracy desired for JWST.

Until recently, the TPF mission was envisioned to be a starlight nulling interferometric instrument that would operate at infrared wavelengths and have a baseline of about 80 meters. Additional examination of extrasolar planet detection strategies and technological alternatives has lead to a number of architectural options that are now under study. The options now range from the original separated spacecraft infrared interferometer to structurally connected interferometers and visible light coronagraphic telescopes.

We have also seen real progress toward an architectural breakthrough in space optical systems. With sufficiently accurate measurement and control, it will be possible to place the elements of a single large aperture on individual separated spacecraft. The requirement is to be able to control a constellation of spacecraft as if they were connected by a rigid structure. It then becomes possible to construct interferometers and sparse aperture telescopes with dimensions that exceed hundreds of meters. These capabilities are being developed by the StarLight portion of the TPF project.

These examples demonstrate the substantial progress made in the technology areas envisaged in



Innovative, lightweight mirrors and support structures will make large optical apertures in space possible while keeping the total mass constant.



our earlier roadmap. Nevertheless, our future technology needs have not yet been met. Staying on the present course is clearly the most likely route to success. We have also had success in identifying common technology needs with other government agencies and developing partnerships and shared resources to find technological solutions.

Building Future Very Large Observatories

Detector Technologies

Detectors, the devices which convert light energy to electrical signals, are the single most important technology which determines the ultimate performance of our observatories. If the detectors fail to do their job, the entire observatory system is seriously compromised. Technologies are poised to

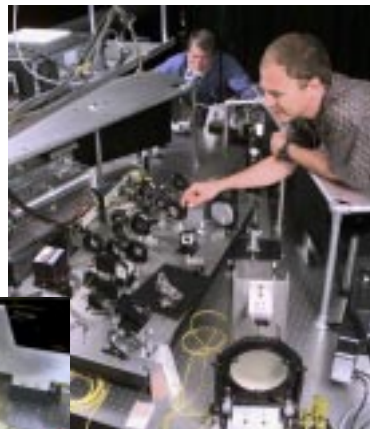
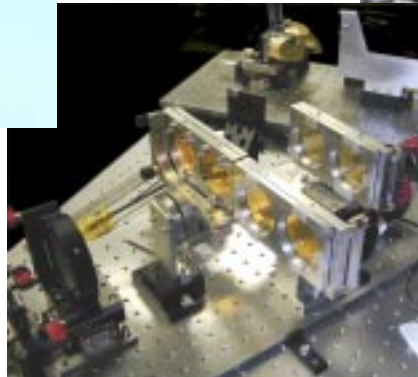
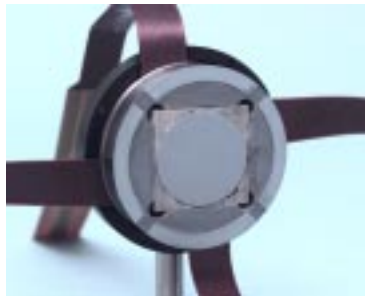
make dramatic gains in detector performance at far-infrared wavelengths and in the ultraviolet. In the infrared, devices have not yet reached fundamental limits, and large format imaging arrays (10^3 – 10^4 pixels) have yet to be perfected. In the ultraviolet, new solid state devices allow simultaneous detection of both the intensity and wavelength of the light. Several technologies should be explored, including semiconducting and superconducting devices, such as impurity band detectors and transition edge sensors for imaging in the 40–600 micrometer band. In addition, very sensitive detectors are needed for spectroscopy, including coherent detectors at the longest wavelengths. It is also in the more extreme domains that productive partnerships with non-astronomical users of detector technology have not developed because there is minimal commercial or military application for the technologies needed by astronomers at long wavelengths.

Detector technologies, while critically important for the large visionary missions of the mid-century, will also enable highly productive, smaller-scale space investigations that might be developed in the Explorer or Discovery programs.

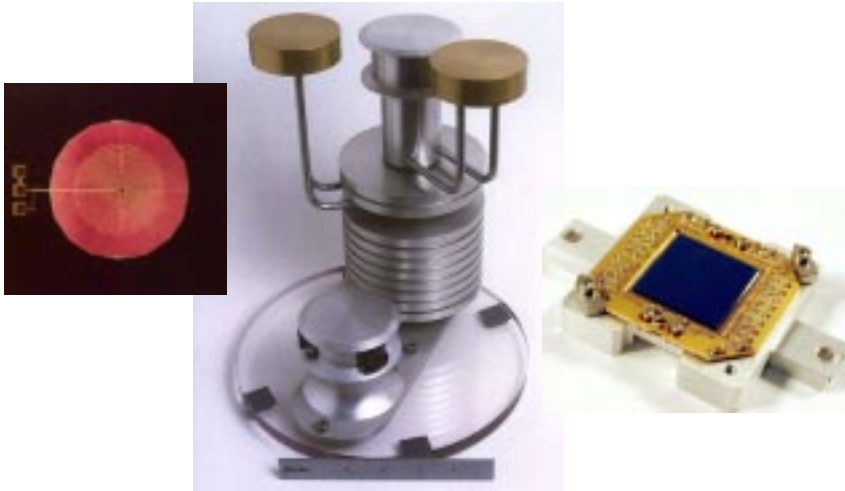
To achieve their ultimate performance, these new detectors will require improvements in small, very low temperature, cryocoolers. In fact, the detector and its cryocooler should be viewed as an inseparable technological pair. The TPF mission is undertaking development of the next level of cryocooler capability; however, the missions of the far future will require further advances to enable detector operation with sufficient sensitivity.

Space Optics Technologies

Usually, the largest and most massive component of a telescope is its primary mirror. In order to launch larger and larger telescopes into space with our current launch vehicles, we must find a way to keep the mass constant as the size increases. This requires new precision materials and structures that allow the mass per unit area, the areal density, of the large optical elements to be reduced. The JWST mirror technology program hopes to achieve 20 kg/m^2 over a 33-square-meter aperture. A 10-meter mirror that has the same total mass requires an areal density about 8 kg/m^2 . Ultimately, areal densities as low as 1 kg/m^2 may be required.



Active wavefront control and ultra-precision laser metrology under development will be key components of future instruments.



Component development of high-performance detectors and cryocoolers lays the foundation for the next generation of observatories.

Active Wavefront Error Control

As the areal density of the optical elements is reduced, they become more flexible and prone to distortions induced from external disturbances. However, the performance requirement on the overall optical system will remain close to perfect in order to achieve the benefits of going to space. This is true even for JWST. As the telescope size increases, there will be a growing need to actively sense and control the shape of the optical surfaces. This will be the only way to ensure the required optical performance as the thermal, gravitational, and mechanical disturbance environment changes in orbit.

Full Aperture Cryocooling

The largest of the Origins observatories will operate at infrared wavelengths. In order to achieve the highest possible performance, the telescope's optics must be cooled to prevent them from being a brighter source of infrared energy than the astronomical targets. Cooling huge telescopes to temperatures close to absolute zero represents an enormous challenge. Observatories that are located at the Earth's distance from the Sun require some form of active cooling to reach the desired temperature of below 15 kelvin. If the telescope could be placed beyond the orbit of Mars, it could be made to naturally cool to the required temperature.

NASA's new nuclear power and propulsion initiative may produce new flight options that will allow space observatories to operate successfully in the outer solar system, eliminating the need for a separate large aperture cooling technology.

Preserving Unique Space Science Technologies

As new technologies appear, we often lose sight of the important and continuing role of the older ones. It is easy to assume that reliable devices will always be there—reality has proven to be different. For example, scientific CCD detectors are no longer always available, optical filter technology was recently threatened by competing pressure for the same manufacturing capabilities, and other spacecraft components are no longer made. And, capabilities required for scientific research are not always of commercial or military interest, as we see in the far-infrared detector case. Where mature technologies exist that are still a critical component of space science missions, NASA must take active steps to ensure that the manufacturing and testing capabilities are preserved. The single most important area is preservation of the technology base for high performance detectors that operate in the visible and infrared. These devices are near their theoretical limits and that capability must be retained.